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A. H. Bunting

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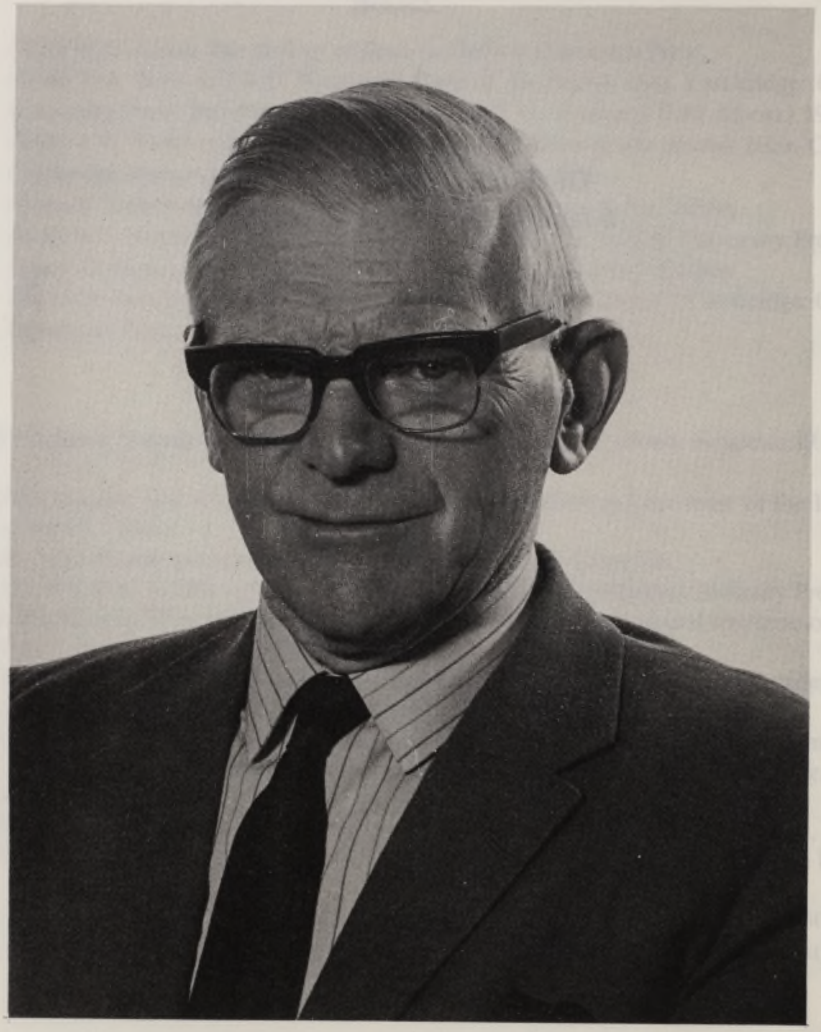

George M. Cooke.

GEORGE WILLIAM COOKE

6 January 1916—10 February 1992

Elected F.R.S. 1969

By A.H. Bunting

GEORGE COOKE joined the Chemistry Department of Rothamsted Experimental Station in 1938. He became head of that Department in 1956, and was also a deputy director of the Station from 1962 and acting director during 1972–3. In 1975 he moved to the London headquarters of the Agricultural Research Council as Chief Scientific Officer. After he retired in 1981, he continued his work from a base at Rothamsted until 1989.

His career covered half a century of vast change in agriculture, in Britain and in the world, in which he was a significant leader.

The years of change, 1938–91

Change in British farming

In 1938, the area of crops and rotation grassland in Great Britain, which had been declining for many years from about 7.3 million hectares (Mha) in 1875, reached its nadir at 4.3 Mha. The total output of cereals, mostly spring-sown, was about 4.6 million metric tons (Mt) per year, harvested from 2.1 Mha at an average yield of 2.1 tons per hectare (t/ha). Of the cereals, the most important was oats (about 2.1 Mt), much of which was used to feed the 670 000 horses which shared the labour of farming with a similar number of humans and about 500 000 tractors. Perhaps 8% of the economically active population worked in agricultural production. The output of wheat was about 1.7 Mt, grown on about 0.75 Mha at an average yield of 2.3 t/ha.

Since then, the rural scene in Britain has been transformed. The area of arable land had returned to 7 Mha by 1975. It has since decreased, as former arable has become grassland, forest or woodland, or has been 'set-aside'. As agricultural prime movers, the horses have been replaced almost completely by tractors, and no more than 2% of the economically active population now work in farming. The output of cereals (increasingly sown in autumn rather than spring) increased to nearly 23 Mt in 1991, produced on about 3.5 Mha at an average yield around 6.5 t/ha. With no farm horses to feed, oats are now a minor crop, but 14.3 Mt of wheat were harvested from 2 Mha at an average of 7.2 t/ha – which, in 1938, many would have thought impossible. 7.7 Mt of barley were harvested at 5.5 t/ha on 1.4 Mha.

The world-wide advance of agriculture

These changes are parts of a larger, continuing, world-wide sea-change in farming, and indeed in biological production generally. In Britain, as in many other countries of Europe and North America, the rural revival was induced in a series of new political and policy conditions, first established to meet the needs of war, and later continued in time of peace. In these new conditions, more productive methods became profitable, particularly on larger farms.

Economically, this policy may no longer be sustainable in Europe. Technically, however, it has been far more than sustainable: it has transformed our understanding of natural environments, particularly in Britain, and vastly increased their productive potentials. It has replaced the partly derelict landscapes and decrepit villages of 60 years ago by a trim and well-managed countryside, even if many hedges have disappeared and much former grassland is now intensively farmed.

Similar advances have spread to many of the poorer nations of the world also. In the developing nations as a whole, the output of cereals increased, between 1948 and 1991, from 310 to 1000 Mt per year, harvested from 317 and 424 Mha respectively, at average yields which have increased from 0.99 to 2.36 t/ha. The output per head of population has increased from 190 to 253 kg per year. Of course much more will have to be done during the coming century, but technically it is clear that the world's farmers are finding out how to do it.

The scientific springs of change

To support these changes, world-wide, science has contributed increasingly more productive and mechanizable crops, many of which are also increasingly resistant to pests and to diseases (particularly those caused by fungi) in the field; improved methods of crop protection (particularly against weeds and fungal leaf diseases); objective physical bases for the management of irrigation; and more productive ways of using terrain and soil, particularly through drainage, liming, treatment of phosphorus-deficient soils, and the use of fertilizers to supply the plant nutrients required by larger crops.

In the management and use of land, in Britain and in the wider world, Cooke became one of the most influential scientific leaders.

George Cooke: background and outlook

Cooke was the son of a Nottinghamshire farmer, William Harry Cooke, and his wife Sarah Jane Whittaker, a former school teacher. He was born in 1916 at Kingston on Soar, in the vale of the Trent.

William Cooke belonged to that central class of English farming people, the tenant farmers and farm managers, who occupied a precarious position, in a time of farming decline, between the landowners and freehold farmers on the one side, and the farm workers on the other. At different times William Cooke farmed rented land for himself, and he managed land and oversaw estate operations for others.

The difficulties of farming and of farming families in the depressed years of the 1930s left indelible marks on his son George. Though he wished at one time to farm for himself, he determined instead to use science to help to improve the life of those who followed the land.

Early years in science and at Rothamsted

From Loughborough Grammar School George entered University College Nottingham in 1935. In two years he took an external degree of the University of London with first class honours in chemistry. He then worked for a year with Professor J.M. Gulland on the use of palladous chloride as a dehydrogenating agent for tetralin and similar cyclic and heterocyclic compounds. This apprenticeship served to develop Cooke's precise, thorough and quantitative habits of work and thought.

He came to Rothamsted in 1938 with a research scholarship from the Ministry of Agriculture to work in the Chemistry Department under E.M. Crowther, a physical chemist with a similarly rigorous outlook. Crowther put him to work on methods to limit the resorption of phosphate when acid extractants were used to determine 'plant-available P' in soils. Although the work was only partly successful, it showed clearly the disadvantages of acid extractants for phosphate, especially in neutral and calcareous soils.

The war years at Rothamsted

When the World War II began, Cooke soon completed his thesis (1940) and left the laboratory for the field to begin his life-work in studies of the use of fertilizers and the profitable management of soils.

After the fall of France in 1940, Britain had to minimize imports, and grow as much of her own food as possible, in order to lessen losses at sea. Together with Frank Yates, F.R.S., Crowther demonstrated, from past experimental results, that this could best be done by using relatively small quantities of fertilizer, and particularly of imported phosphates, to increase the output of home-grown crops (Crowther & Yates 1941). Much of the wartime work in the Rothamsted Chemistry Department was designed to find out how to use these fertilizers, and other possible sources of phosphate, most productively.

The field experiments

Cooke's role in this was to set up and control very large numbers of field trials of modern design in many places in Southern England. He worked in the fields of farmers, with their material and intellectual cooperation, as Crowther and H.V. Garner (from whom he and many other field workers learnt their craft) had done in the 1930s, in a large and pioneering series of experiments on the manuring of sugar beet.

The experiments were located and conducted with the help of regional and county agricultural chemists and farm advisers. Cooke and others from Rothamsted travelled to them by train, carrying pegs, string, measuring tapes or chains, biscuit tins (for samples), and even more recondite equipment, in a cricket bag provided by Garner, often together with numerous paper bags containing the fertilizer dressings for individual plots. Later, an aged war-surplus van, and more cricket bags, were acquired, but the pattern of the field experimenter's life continued, in the open in all weathers, fuelled by beer, meat pies and meals in transport caffs, of which Cooke compiled the equivalent of a Michelin guide. Many dedicated field experimenters first learnt to enjoy not only the sustaining virtues of an English breakfast at the end of a windswept day in the Fens with Cooke, but also the elegance and logic of experimental designs, and the keen pleasure of unfolding their orthogonal symmetry in the field, in the bucolic camaraderie of this peripatetic golden age.

The experiments measured, usually against standard superphosphate response curves, the effects on yield of phosphate supplied by various possible substitutes for superphosphate. They included steel-making slags, and rock phosphates of different kinds, ground or processed in different ways. Since sulphur was in short supply during the war and was expected to continue so after it, the trials also tested silicophosphates, in a cooperative programme with the Ministry of Supply which included more than 400 field experiments (e.g. 17, 18, 24, 25, 26).*

Other experiments measured the phosphorus and other nutrients supplied by various organic wastes, including town refuse and sewage sludges, as well as organic manures including composts, farmyard manures, hoof and horn meals and leather wastes.

Work in glasshouse and laboratory

The field experiments on sources of phosphate were linked to extensive pot trials in the glasshouses at Rothamsted, which were managed by Elizabeth Hill, whom George Cooke married in 1944. In the laboratory, thousands of samples of soils and other materials were analysed under the meticulous direction of R.G. Warren, a central pillar of the whole enterprise.

Fertilizer placement

The phosphate in fertilizer is absorbed by soil and moves hardly at all from the point at which it is applied, unlike potassium and, especially, nitrogen fertilizers, which are more mobile. Almost a century earlier (1847), the founder of Rothamsted, Sir J.B. Lawes, F.R.S., had shown that superphosphate drilled close to turnip seed was more effective than the same amount of fertilizer spread on the surface and worked into the soil.

Just before the war, and in its earlier years, considerable numbers of grain drills fitted with fertilizer hoppers were imported from North America and Australia. Such drills allow seed and fertilizer to enter the soil together, through the same coulter. Many farmers found combine drilling useful, particularly for reclaiming phosphate-deficient land ploughed from old grass.

In 1940 Crowther and Cooke started to test combine drilling as a way to eke out scarce supplies of phosphate and other fertilizers. In cooperation with agricultural engineers, Cooke continued the research for a decade after the war, and extended it to placement drilling, in which fertilizer is placed a few centimetres below the seed and to one side. Both placement and combine drilling can increase yield, especially of short-season crops and on nutrient-poor soils (170–195, 197, 237–244). As decades of high farming have lessened the

* Numbers in this form refer to entries in the bibliography on the accompanying microfiche.

area of such soils, placement has come to be used mainly for early-maturing horticultural crops (e.g. D.J. Greenwood, F.R.S., and Neetson 1992).

Head of Chemistry Department, Rothamsted

During the war, and for a number of years after it, much of the work of the department, and of Cooke himself, was concerned with short-term practical questions about fertilizers for crops and grass. But to sustain the fertilizer revolution into the distant future, in Britain and in the wider world, longer-range and more analytical enquiries (for which Rothamsted provided an unique background) would clearly be needed.

For Cooke, as for Lawes and his close colleague Sir Henry Gilbert, F.R.S., perceptions of this kind were part of the countryman's in-built sense of the continuing forward march of time, through the changing seasons and years, and of their effects on the land and other enduring features of the countryside. These thoughts anticipated by many years the current popular interest in sustainability and in effects of farming on the environment.

The necessary enquiries fell into two broad and overlapping classes – analytical studies of the cumulative and residual effects of fertilizers and management (including grass courses and organic manures) on the soils of long-continued field experiments at Rothamsted and elsewhere; and studies of the forms, transformations, movement and fate of compounds and ions containing nutrient elements in soils and biological production systems, as well as of unexpected or unwanted effects of these materials outside the systems.

So an increasing number of able younger workers, and many new techniques, including the use of isotopes for studies of nitrogen, phosphorus and potassium, were added to the staff and resources of the laboratory. Work in the field was strengthened for the experimental analysis of longer-term effects. The new recruits included (the late) G.E.C. Mattingly, A.E. Johnston, P. Arnold, and F.V. Widdowson.

Cooke continued these trends when he was appointed head of the department in 1956. His earliest appointments included J.K.R. Gasser and R.J.B. Williams. D.S. Jenkinson, now F.R.S., joined in 1957 to work on organic matter in soils.

Cooke's work henceforth had four main components: the continuing development of the department; the advancement of knowledge, and particularly of his own knowledge, of soils, environments and biological productivity; the dissemination of all he learnt from research and scholarship to all who could use it; and his personal concern with the problems presented by the long-term experiments at Saxmundham in Suffolk which are reviewed below.

He supported and influenced the expanding and increasingly diverse longer-range work in the department, more by encouraging, cajoling or persuading his colleagues than by 'directing' them. He took no direct part in it. The programmes were devised and the results were published by his colleagues, so that his personal interest and support is not reflected in the list of his publications. Moreover, though he shared his more applied work with several colleagues, fewer and fewer of his papers were written jointly with them.

Reviews and books

Cooke based all his work on a thorough knowledge of what was already known. Throughout his working life he read, recorded and summarized the professional and practical literature of the fields with which he was concerned. He wrote, often by invitation in later years, many comprehensive, synoptic and interdisciplinary reviews of important technical topics, frequently world-wide in scope.

This was a continuing task of enormous size. For example, during 1972–83, the keyword 'fertilizer' drew out an average of 6000 titles a year from the database of the Commonwealth Agricultural Bureaux (now C.A.B. International). Cooke wrote reviews to impound this flood – on fertilizers supplying phosphorus (e.g. 24, 34, 104), nitrogen (10, 11) and potassium (38, 41, 50); and on organic matter in crop production (97 (with H.V. Garner), 101).

Cooke's masterly book *The Control of Soil Fertility* (1967 (70)), brought together information from more than 660 publications, from many countries, on the use and abuse of fertilizers. This book was widely used for many years; it became a standard university text; it was distributed abroad by the British Council; and it was translated into Russian, Hungarian, Bulgarian and Arabic.

His earlier work *Fertilizers and Profitable Farming* (1960, 1965 (112)) was replaced by the more extensive *Fertilizing for Maximum Yield* (1972, 1975, 1982 (138)). Though it is perhaps more didactic, it none the less contains a bibliography of 267 references.

Developments in fertilizer use and technology

Work on fertilizers is never static: specifications change as new crop varieties and fertilizer materials appear, and policy and management evolve. Thus the nitrogen fertilizer dressing recommended for spring wheat today is double the 70 kg that Cooke advised in 1959.

Cooke promoted tests, mostly made by others, of new and experimental fertilizer products including liquid fertilizers and aqueous ammonia, slow-acting fertilizers containing nitrogen and phosphorus, and of inhibitors of nitrification, intended to lessen the risk of leaching of nitrate by delaying the nitrification of ammonium ions in the soil.

The assessments of these materials were borne out by the experience of farmers. Liquid fertilizers now represent about 8% of the market, and slow-release fertilizers have a place in horticulture, but the others have had little lasting effect in Britain.

Though practical farmers are more concerned with profit than with yield, Cooke as a scientist was interested in trials designed to find out how to maximize yield, particularly by exploiting positive interactions among nutrients and between nutrients and other inputs, particularly more responsive crops (154). A factorial maximum yield trial, designed to define response surfaces, is a powerful means not only for describing environmental resources and constraints, but also of suggesting practical recommendations.

Fertilizer research and soil survey

In all of his work Cooke wished to associate effects of fertilizer and other treatments with particular kinds of soil. At first, he found the methods and categories of the Soil Survey of England and Wales too time-consuming and too detailed for his purpose. As a result he and others in the department often described soils in ways which the Survey regarded as imprecise, erroneous, or both. But as the Survey developed, his appreciation and support of it developed also. He was a member of the Soil Survey Research Board from 1962–66 and from 1969–73, when it was disbanded. At the Agricultural Research Council after 1975 he was unstinting in his support, and he continued his interest after his formal retirement.

Nutrient elements and ions, and their fate in soils and crops

The relationships between the chemical, physical and biological properties of soils, on the one hand, and the effects of applied nutrients, on the other, are a classical question of soil chemistry and the science of soil fertility. For Cooke, studies of the diverse and changing forms in which nutrient elements, and their compounds and ions, occur in soils, and of their balances, movements, cycling and fate, offered a dynamic means to approach this question.

So work developed in the department and elsewhere, on the ways in which phosphate and potassium were held, accumulated and released in soils (Mattingly and Talibudeen, using radio-tracers), and on effects of excess soil manganese and of nutrient ratios on the uptake of phosphorus in some tropical soils (P.H. Le Mare).

The most important and least tractable of these topics concerned nitrogen in the soil. Nitrate and ammonium ions do not accumulate in soils in temperate climates, yet often less than half of the nitrogen applied as fertilizer is recovered in the harvested crops. Nitrogen is lost as nitrogen gas, ammonia, oxides of nitrogen, and nitrate, but it has been difficult to quantify or predict the losses.

The leaching of nitrate was an old topic at Rothamsted. Cooke produced some widely cited data from Saxmundham (below). When the heavy soils there were effectively drained, the drainage could contain up to 10 mg nitrate-N per litre, which is close to the European Community's limit for nitrate in drinking water. Larger values have been found in leachings from light soils, and after fertilizers have been inappropriately applied in spring. Losses from cut grassland are smaller, though they may be appreciable from grazed grass in winter and early spring (75). The loss of nitrogen from the decomposition of organic matter when grassland is ploughed is often substantial and may continue for many years. In all of this work effects of soil physical conditions and weather are significant.

But leaching is only one of several routes of loss (The Royal Society 1983). Cooke's colleagues, including P.B. Tinker, R.K. Cunningham and T.M. Addiscott, were thwarted in their earlier studies for lack, at that time, of effective techniques to identify the forms in which nitrogen is lost, and to measure denitrification and the leaching and turnover of nitrogen in the field. The department waged and lost a long war with a recalcitrant mass spectrometer.

When more effective methods and equipment became available, D.S. Jenkinson used labelled carbon and nitrogen to study the long- and short-term changes in nitrogen compounds and organic matter in soils, including the effects of grass. Much of this work was linked to the modern utilization of the long-term experiments (below).

Losses from agricultural systems and effects on environment

The work on leaching led naturally to studies of larger-scale losses of nutrients (147) and of unexpected or unwanted effects of new farming methods on environments in Britain, with which Cooke had first become concerned in the early 1950s. With Williams, he studied the leaching of nutrients into rivers and underground aquifers. They found that little phosphorus came from agricultural land except through erosion (35).

Important losses and risks arose in animal production. Even in 1973, animal excreta in the UK contained 0.9 Mt of nitrogen, 0.2 Mt of phosphorus and 0.7 Mt of potassium (100, 140). In 1988–90, the nitrogen in animal excreta was nearly 1.5 Mt per year (Addiscott, Whitmore & Poulson 1991). As the numbers of animals, and particularly of intensively housed animals such as pigs and poultry, increased, the collection, storage, handling and use of their wastes (154) had to be managed so as to avoid waste and pollution and to minimize undesired effects such as the smell of newly spread pig slurry.

Corresponding but smaller problems arise in the disposal of human excreta, as the Rivers Pollution Committee (of which Sir John Lawes had been a member) had pointed out in 1874.

Fertilizer compensation tables and the residual value of fertilizers

The studies of the fate of applied nutrients were directly relevant to the compensation of outgoing tenants for improvements they leave behind them. Since 1913, 'tenant right valuation' has included an element for the value of residues of water-soluble phosphorus and potassium fertilizers and of liming materials. Cooke exhaustively reviewed all the data he could find on these topics and concluded (127, 136, 199) that the tables in use gave a measure of sound, but perhaps rough, justice. While it might be possible to produce more sophisticated tables that would be more precise scientifically, they might prove unworkable in practice.

Residual effects, especially of phosphate, could often be seen in spring in fields at Rothamsted which had received no new fertilizer for many years. Laboratory and field studies to evaluate these effects had begun in the 1950s (Warren, Johnston). Cooke promoted this work, not only because of its intrinsic scientific interest, but also because it would help agricultural valuers to make due allowance for past applications of phosphate and potash, and farmers to save the cost of unnecessary new applications.

From past experimental and practical experience, he concluded (e.g. 154) that with adequate fertilizers, many soils in Britain and other countries of temperate climate can grow arable crops continuously without any irreversible damage. The requirements for nitrogen fertilizer (which are difficult to predict from measurements on soils or crops) are profoundly affected by previous cropping, while levels of residual phosphate and potassium must be maintained above certain minimum values to ensure acceptable yields and responses to newly applied fertilizers. For more than 25 years an 'N-index' system, using past agronomic information, has guided advice to farmers on nitrogen fertilizers. For the other main nutrients, fertilizer practice now uses fresh applications primarily to maintain the residual phosphate and potassium status of soils, as determined by soil analysis.

Farming and organic matter

The work at Rothamsted was concerned from the start, 150 years ago, with the experimental analysis of the effects of farmyard manure. The records of this work constitute the most complete repository in the world of quantitative scientific information about organic matter in farming systems.

Discussions of organic matter in agriculture usually involve three intertwined but separate questions. The first is how best to use the nutrients contained in plant and animal residues. Cooke stressed that it is important to recycle the nutrients held in such materials, but pointed out that organic manures were not only more costly to handle, but were also intrinsically more likely than inorganic fertilizers to pollute air and water.

The second question concerns the long-term effects of different farming systems on soil organic matter and yield. Firmly but cautiously, Cooke concluded, from the results of the long-term experiments, mostly on the experimental farms at Rothamsted and Woburn, that 'experiments done during the last forty years show that most British farmers need take no special action to add extra organic matter to their soils if, by doing so, the profitability of the system is lessened. If adequate fertilizers are used, organic matter will be maintained at sufficiently high levels in most soils by most crop residues: the crops that are most profitable may be grown if weeds, pests and diseases are controlled. In many other countries where soil deterioration under arable cropping may be a serious cause of loss, there is unfortunately, no evidence on this question' (160).

It became evident in the 1970s and 1980s that there are circumstances in which the benefits of fertilizers cannot fully be realized unless the status of organic matter in the soil is also satisfactory. Cooke suggested that 'the (additional) gains from organic treatments are associated with the provision of nitrogen for crops in ways and at times that are not fully imitated by fertilizers used in conventional ways' (154).

However, the answer is often more complex. Arable farmers are well aware of an intangible soil property called 'tilth' and know well how even a small amount of organic matter in a soil can stabilize it. Earlier work had found that while in general much of the effect of organic manures was associated with the plant nutrients they supplied, on some sandy and silty soils the positive effects of fibrous organic manures could not be obtained with unstructured organic materials or with inorganic sources of nutrients. Williams and Cooke used simple quantitative tests of 'structural stability' to demonstrate, on a wide range of soils varying from sands to heavy clays, that a period under grass was much more effective in restoring the stability of topsoils than even lavish dressings of farmyard manure, though the improvements did not last long when the soils were brought back into arable cultivation (99).

The third question is usually bypassed, rather than explored, by dogmatic assertions that 'organically grown' produce is 'better' in some (usually unidentified) way than produce grown with appropriately used inorganic fertilizers. When this was claimed, Cooke would demand to see the evidence, so that he could test it rigorously and scientifically. He was similarly scornful of such judgmental phrases as 'ecologically sound and balanced agriculture' – if anyone claimed to know of such a system, he wanted to find out all about it, try it himself, compare it with other systems, and test it rigorously for leakage of nutrients, sustainability, profitability and so on (235). Though he did not accept all the reported conclusions, he was interested in the careful field work on these questions which he had seen at the Pye Research Centre at Haughley in Suffolk.

The long-term experiments at Rothamsted

The 'classical experiments' at Rothamsted are the large field experiments started by Lawes and Gilbert between 1843 and 1856 to analyse complex agronomic questions, particularly the effects of management and manuring on crops and grass. Eight of these still continue, with many of their manuring treatments unchanged. On these plots the treatments, measurements and observations have been meticulously maintained and recorded for up to 150 years.

Though the experiments on arable crops were set out on sites which had previously received as much as 250 t/ha of chalk, the long-continued use of ammonium sulphate was making the plots increasingly more acid (though of course not so dramatically as on the light land at Woburn) so that yields and responses to plant nutrients were being affected. After 1954, the acidity was gradually corrected, and from 1958 onwards the treatments and cropping were modified in stages to extract more information about the nature of change over time in the soils and crops of these old experiments.

Today they are making more significant contributions than ever to knowledge and thought about agronomy, soil science, 'sustainability' and environmental change. So, for example, Jenkinson's detailed measurements and mathematical models of change with time in carbon and nitrogen in the organic matter of soils, were based on the classical experiments.

From 1956 to 1975, as a member (and chairman from 1971–5) of the Rothamsted Field Plots Committee, Cooke contributed substantially and influentially to thought about the evolution of these historic test-beds for hypotheses and concepts old and new.

The long-term experiments at Saxmundham

In 1964 Rothamsted became responsible for the long-term experiments at Saxmundham in Suffolk which had been started in 1899. Garner and Cooke had been interested in them (along with their light-land counterparts nearby at Tunstall) since the early 1940s.

The Saxmundham soils are mapped as the Beccles series, a complex sandy clay loam overlying in turn a slowly permeable clay, from which calcium carbonate has been leached, and the chalky boulder clay. These difficult soils cover large areas in eastern England.

Saxmundham is in one of the driest parts of England, yet (to quote Oldershaw, who ran the experiments for 36 years) 'this heavy land is frequently so wet that neither horses nor men can walk on it'. The soil was managed with special, locally made equipment, on a narrow ridge (stetch) and furrow system. Yields on the experiments were small, like those of neighbouring farmers. Winter wheat given nitrogen, phosphorus and potassium fertilizers gave an average of no more than 2.4 t/ha of grain from 1920 to 1939. Yields with farmyard manure were no better. Between the wars, much of this 'four-horse' land had become derelict as poor pasture and scrub.

Cooke, who understood Mao's dictum that there are no poor soils, only poor farmers, and believed that a productive soil could be made out of almost anything, given enough work, was challenged by the small yields on these soils. Saxmundham offered a difficult but practical research task in which he could work himself, alongside several of his colleagues.

It soon became clear that yields were limited, not by lack of plant nutrients but by the physical properties of the soil (78). In the end, an effective soil drainage system, together with cultivations designed to minimize compaction – shallow ploughing, followed by carefully timed power harrowing and early sowing in autumn – and correct management and rotation of the crops, multiplied the yields by four. Towards the end of the project the yields at Saxmundham were often larger than the best at Rothamsted (55, 65, 69, 72, 74, 77, 79, 82, 88).

While this work was going on, Cooke was an extremely busy man, at the height of his career. Yet every hour he could spare was spent at Saxmundham. When his colleagues drove over early from Rothamsted to start their day's work on the experiments, they often found Cooke there already, inspecting the plots after spending the night in a sleeping bag in a corner of a former road-man's caravan on the site.

Later years

In 1972 Cooke suffered a serious hip injury in a car collision caused by an irresponsible youth who escaped with very minor injuries. This made him progressively less mobile and gave him increasing physical pain, so that it became more and more difficult for him to work in the field or to travel.

Though, after 1975, he was no longer responsible for experimental work on fertilizers and soil management, he did not abandon the subject. As long as he could, he maintained his interest, scholarship and thought. To the end of his working life he spent much of his nominally spare time in the Fertilizer Building at Rothamsted, which had been the base of his personal work for many years.

Chief Scientific Officer, Agricultural Research Council, 1975–81

In 1975 Cooke moved from Rothamsted to the headquarters of the Agricultural Research Council (ARC) as Chief Scientific Officer to two successive Secretaries, Sir William Henderson, F.R.S., and Sir Ralph Riley, F.R.S.

Cooke joined the headquarters staff of the ARC at a peculiarly critical time of great change. The 'customer–contractor' principle introduced by Lord Rothschild, F.R.S., had been intended, through transfer of funds and a consultative machinery, to make the Ministry of Agriculture into a perceptive and adequately funded purchaser of research services from the Council and the stations it maintained.

At the same time many aspects of the Council's interests in crop production were changing. Some work appeared to be sufficiently advanced to be carried forward by industry, by the advisory services and by farmers themselves. Attitudes to longer-term work on the management and fertility of soils were changing. New fields of work, particularly those based on molecular biology, required vigorous support. The environmental effects of farming, real and imagined, were ever more pressing. Europe was now closer than ever. And it was easy to point to apparent duplications and imbalances in the research effort.

In addition, the Council and the staffs of the research stations were facing a most difficult central question – what were the future tasks of research in an industry in which earlier work had been so successful that it was now producing more output than was needed, at an increasingly unacceptable total cost? Few seem to have realized that this question is real and has to be answered.

Whatever improvements the new arrangements might have achieved were offset, about 1978, by increasing restrictions on government spending which led to severe decreases in agricultural research. Stations were closed and staff made redundant in the services of both the Ministry and the Agricultural Research Council.

The work for which the Council was responsible now started to undergo a substantial managerial reorganization. The activities in those of the stations which had survived were distributed among a small number of national institutes, henceforth known by unmemorable acronyms, whose responsibilities might be scattered at different centres many hundreds of miles apart.

These changes inevitably cut across both careers and loyalties. In the earlier stages it fell to George Cooke and his group of scientific advisers, to guide and counsel so as to minimize damage and maintain morale. Cooke knew well the purposes, personnel, resources and difficulties not only of the research service, but also of the Ministry, the farming community, and the supporting industries. He was trusted as a man of sense and integrity by all parties. His sympathetic understanding and constructive advice did much to ease the pains of transition. In this troubled period he further justified the C.B.E. which had been conferred on him in 1975 in recognition of his services to agriculture and agricultural research.

International interests

Both at Rothamsted and at the ARC, Cooke maintained active interests in overseas agriculture. He attended the meetings of the International Society of Soil Science, though on one occasion in New Zealand it is said that he deserted a soils tour in the North Island in favour of a foray with Norman Pizer, the advisory chemist at Cambridge (with whom he had had substantial differences on professional topics) to investigate the reputedly superior beers of the South Island.

During the 1950s and 1960s, Rothamsted trained numbers of entrants to the overseas services in agricultural science (including several Colonial Office scholars), and received many workers from overseas as shorter or longer term visitors. Cooke kept in touch with many of them by visits and correspondence, so that many otherwise isolated workers could feel that they were valued members of a world-wide invisible college.

From 1962 to 1978 he was a consultant in agricultural chemistry to the soils division of the Rubber Research Institute of Malaysia, and regularly attended meetings at Kuala Lumpur. He was also a consultant in soils to the Empire Cotton Growing Corporation/Cotton Research Corporation during 1972–3, and to the Ministry of Overseas Development for work in East Africa from 1975 to about 1980.

As a member from 1962 to 1986, he had a substantial positive effect on the proceedings of the Scientific Board of the International Potash Institute, Berne. The reviews he wrote for successive meetings of the Institute (39, 47, 50, 51, 76, 80, 94, 150, 228) are among his best.

From 1976–9 Cooke was a member of the Board of Directors of the International Fertilizer Development Centre (IFDC), Muscle Shoals, Alabama, and chairman of its programme committee for developing countries. He continued as a consultant to 1986. During this time IFDC was pursuing studies of rock phosphates (36), on which he had worked 25 years before.

Cooke was an occasional consultant to the European Community and to the Food and Agriculture Organization of the United Nations (FAO).

Among his most significant international interests were his associations (supported in many instances by the Royal Society) with soil scientists in Eastern Europe, particularly in Bulgaria, Hungary, the former Yugoslavia, Czechoslovakia and USSR. Reciprocal visits included periods of work at Rothamsted by colleagues from these countries. Cooke was appointed a foreign member of the Lenin All-Union Academy of Agricultural Sciences of the USSR in 1972. Nearer home, he was appointed an honorary member of the Royal Irish Academy in 1980.

Dissemination

For Cooke, research was not complete until its useful results were disseminated. He published many scientific papers, and he was an editor from 1960 to 1979 of the *Journal of Agricultural Science*, Cambridge. But equally important for him was the direct communication of the results to those who could use them.

Links with the Ministry of Agriculture, Fisheries and Food and other official agencies

Since the days of Lawes and Gilbert, Rothamsted had been an important source of information and advice, first to the Board of Agriculture and later to the Ministry of Agriculture, Fisheries and Food. As World War II approached, the experimental work of the Chemistry Department, and the seminal paper by Crowther & Yates (1941) on fertilizer policy in wartime, led it directly to a central role in advising on policy and practice for the fertilizer revolution.

Cooke's most important links with the Ministry were through personal friendships and mutual respect based on common, shared outlook with many of his official colleagues. He became readily accepted by many in the Ministry as a partner who happened to be a scientist.

Many of these friendships were of long standing. For 35 years he had worked closely with soil scientists and advisers in the regions and counties and in the Ministry, during the war and in the exciting years of reconstruction that followed. During most of this time he knew personally every soil chemist and soils adviser in the National Agricultural Advisory Service/Agricultural Development and Advisory Service.

Links with the agricultural and fertilizer industries

Cooke followed the tradition of Augustus Voelcker in Britain and Georges Ville in France by promoting a close liaison between soil scientists, practical farmers and the fertilizer industry.

He exerted much of his influence in the professional societies and associations of the industries. As chairman of the Agriculture Group of the Society of Chemical Industry from 1956 to 1958 (and secretary for part of the time) he was able to preserve it and ensure its later success. In 1983 he received the Society's Medal and delivered a forward-looking lecture on the future contributions of the industry to crop production (90).

In the Royal Agricultural Society of England, Cooke was elected to an honorary fellowship in 1981. He had written for the Society's journal since 1952. From 1956 to 1973 he wrote the accounts of soils and fertilizers included in the 'Current Reviews' section of the annual 'Farmers' Guide to Agricultural Research' in the Journal. In 1967 he was awarded the Society's research medal, and in the same year he contributed two papers, one on fertilizer residues (127) and the other on the history of advice on fertilizers (128).

The NPK Club is a dining club of limited membership, formed in 1945 to continue informally the partnership which had been established during the war years between members of the Fertilizer Allocations Committee of the Ministries of Agriculture and of Supply, and the conference of Advisory Chemists. Its members and guests were and are all active and influential in relation to soils and soil fertility, and they come from official, academic, industrial and research backgrounds. Cooke was elected a member in 1955. He was chairman in 1966 and secretary in 1982–3. The brief history of the club that he wrote for members in 1986 illuminates the working of that very British institution, the informal but powerful inner cabal in a field of common interest.

The Fertilizer Society brings together a wide range of people who work in or in other ways support the fertilizer industry. George Cooke joined the Society in 1947 and was active in it through the rest of his working life. He presented six papers at meetings – more than any other contributor. He was vice-President in 1960–1, and President in 1961–2. In 1971 he received the Francis New Medal of the Society and in 1979 he was made an honorary member for his services to the society and his eminence in the field.

Cooke was a member of the Farmers' Club, and he and his wife seem to have enjoyed the company they found there. One of his best reviews on crops and fertility (57) was prepared for a lecture to the Club.

Lectures

George Cooke was not an orator but he had a splendid voice and was a remarkable lecturer. His lectures were factual, practical, logical, precise and convincing. They were expertly constructed and illustrated and illuminated appropriately by touches of sly humour. The lectures he valued most highly were given to farmers and their associations all over Britain. Although as the official advisory services evolved, there was less need for such lectures, he remained 'the best draw in the business'.

He also lectured widely in Europe, particularly in Eastern Europe and the former USSR. From 1980 until 1988, he spent a week each year at the Instituto de Edafologia y Biologia Vegetal in Madrid, to deliver a series of lectures (which he took over from E.W. Russell) on advances in soil science and their practical application, in an international course on soil fertility and plant nutrition directed by Professor V. Hernando. The Spanish translations of these lectures appear to have provided a useful link between British soil science and the Spanish speaking world, especially in Central and South America.

In Britain, he gave many prestigious lectures – the Farmers' Club Lecture (1959), for which he was awarded the Silver Cup for the best paper presented at a meeting in that year (57); the Amos Memorial Lecture at East Malling Research Station 1967 (71); the Francis New Memorial Lecture of the Fertilizer Society 1971 (137); the Clive Behrens Memorial Lecture, University of Leeds 1973; the Scott Robertson Memorial Lecture, Queen's

University Belfast 1973 (140); the T.B. Macaulay Lecture, Macaulay Institute for Soil Research 1979 (156); the G.E. Blackman Memorial lecture, University of Oxford 1980 (157); and the Boyd Orr Memorial Lecture of the Nutrition Society 1981 (87).

Scientific societies

His election to the Fellowship of the Royal Society in 1969 both surprised and touched Cooke. It was deeply pleasing to him, as a scientist concerned with practical problems, to find that his work was valued as a significant contribution in the application of science.

Though Cooke was a Fellow of the Royal Institute of Chemistry (later the Royal Society of Chemistry) and of the British Grassland Society, he appears to have played an active part in one strictly professional society only: the British Society of Soil Science. He joined the Society in 1952, was later a member of Council, and President in 1976–8. His distinguished presidential address (154) is for many a landmark in the development of applied soil science. Through the Society he was a member of the International Society of Soil Science, mentioned above.

Papers for farmers and advisers

Cooke was prolific and precise as a writer in the farming press for farmers and their advisers. His aim was not to publicize agricultural science, important as he knew that to be in a world increasingly hostile to both science (particularly chemistry) and agriculture, but, like Lawes (1856), 'not exactly to put money in my pocket, but to give you the knowledge by which you may be able to put money in yours'.

The 39 papers listed in this class (237–275) were intended for use, not for ostentation. They are not bagatelles: each has a specific didactic purpose, which it achieves clearly and economically.

George Cooke, the man and the scientist

George Cooke was a countryman at heart. His guiding purpose was to prevent British farming and farmers from falling back into the state he had known as a boy. He was readily accepted by farmers as one of them, even if he came bearing the tools of science. He was widely known, so that in farming company, his progress could be slow – he once said on a showground that it had taken him two hours to walk 150 yards.

In his prime, he was a tall and powerful man who enjoyed practical work on farm or allotment, and was proud of his ability to lift and carry heavy sacks of produce or to toss bales into a cart with a pitchfork.

He had a capacious memory and a remarkable capacity for broad synoptic thought, which gave his professional assessments and technical reviews their unique quality. They also made him an outstandingly competent chairman, particularly of gatherings spanning many disciplines. He directed them with skill and understanding and summed up at the end so that all participants felt that their contributions had been valued and correctly related to the others.

By nature Cooke was kindly and courteous, though his fuses were often short. He was properly suspicious of the new, particularly if it was presented in flashy or promotional garb.

But he was always ready to comprehend it if it was both honest and comprehensible, and to accept it if it could pass his challenge at 95% probability or better. He did not gladly suffer fools, or the pretentious, or the many charlatans who pontificate about rural life, work and 'the environment', and, perhaps particularly, about soils.

At the same time, he was quick to recognize and support originality and merit, particularly in the young and unrecognized, often against criticism from more established or less imaginative seniors. His occasional apparent impatience with abstract or academic topics often hid the fact that he admired research which was timely, and intellectually and technically sound, whatever its subject.

Cooke was a curiously private man, not exuberant or extrovert, content to work long hours on his own. Perhaps he had few truly close friends, but there were many whose friendship he valued and who enjoyed his company and look back on him with affection and pride.

In his own work he was quantitative, meticulous, self-critical and unremittingly and prodigiously industrious. He would return to the laboratory from a day in the field, as others were setting off for their homes, and go straight into his room to start on his evening's work. He could be formal enough on formal occasions, but at work (at least at Rothamsted) visitors sometimes mistook him for a farm worker who had strayed into the office or laboratory by mistake.

The ascetic pattern of his life and work depended during nearly half a century on the support of his wife Beth and their children Harvey-Jane and Benjamin. He was devoted to them, and they to him. The home Beth maintained was essential to his effort. He could not have done what he did, particularly in the later years, without her support at home and on his journeys abroad. Nor could this memoir have been written without her understanding of his endeavour, and her devoted work in assembling and listing his publications.

His relaxations were few. He and Beth shared a narrow boat on the Midland canals. His usual duty as helmsman gave ample time for thought – invariably, no doubt, about weighty matters – and for the rare experience of doing nothing, even though some suspect that he salved his conscience by collecting samples of water as he went along for determination of nitrate and other pollutants.

Assessment

George Cooke has an assured and unique place in the history of agricultural science in Britain. His work rested on a century of endeavour, established by Lawes and Gilbert, on the chemical aspects of the production of crops and stock.

Cooke inherited this notable but still incompletely utilized tradition. With the new policies demanded by the war and continued after it, he helped to realize the fertilizer revolution in Britain, and to spread it to Europe and the wider world. He was the right man in the right place at the right time. Some have seen him as one of the last survivors of that endangered species, the agricultural chemist.

The success of the fertilizer revolution in Britain has been so complete that what remains of the original task can now be carried forward by the field services, the industries, and the farmers themselves. On the other hand, the methods, concepts and experience of the revolution can now be used to advance the next phase, made necessary by the very successes of the preceding one.

In this phase, rural life and the rural landscape of Britain will adjust to changes in land use, and more productive uses of energy of all kinds will be required. Even more important will be research and training to support the sustainable management of the environments of the world during the coming century, as the effective demand of increasing numbers of humans requires that biological output be trebled.

Cooke's death marked the end of the older era. When he entered the nursing home in which his life drew to its close, he took with him the portraits, not only of Beth and their children, but also of Lawes and Gilbert. So the founding fathers looked benignly down, across a span of 150 years, on the final days of their outstanding successor.

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The complete bibliography appears on the accompanying microfiche. A photocopy is available from the Royal Society at cost.